Multiscale Traffic Processing Techniques for Network Inference and Control

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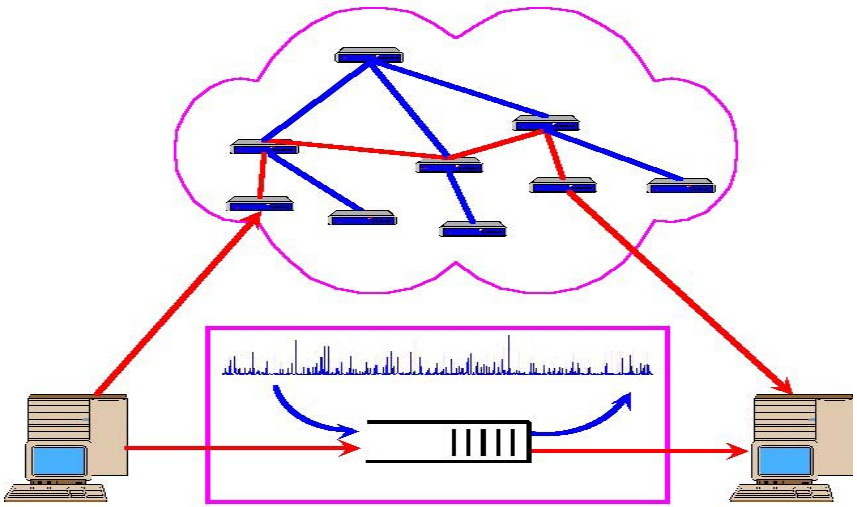
Effort 1

Chirp Probing

Objective: Reduced complexity, multiscale link models with known accuracy



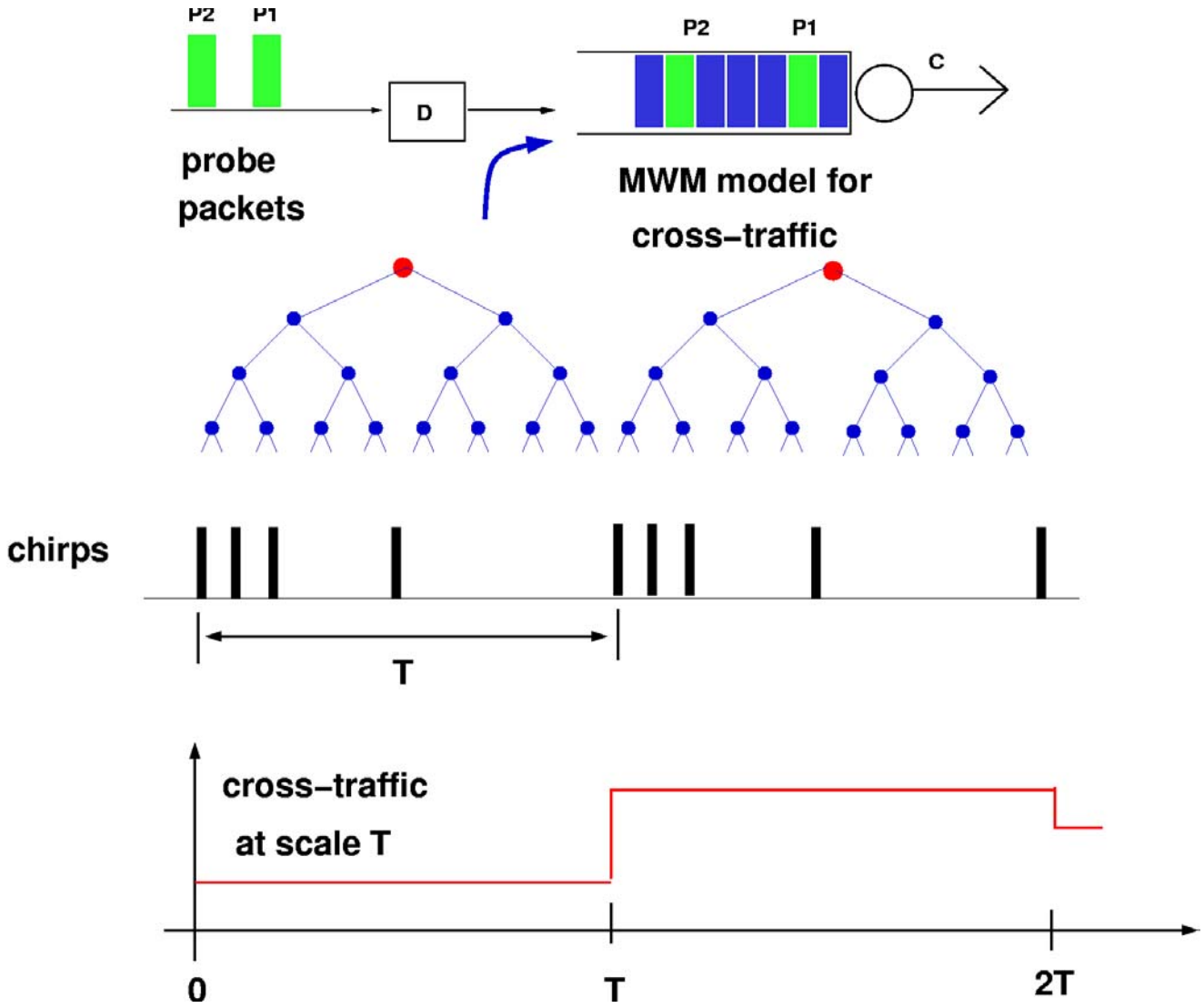
Innovative Ideas

- Multifractal analysis
- Multiplicative modeling
- Multiscale queuing
- Chirps for probing

Impact

- Congestion control
- Workload balancing at servers
- Dynamical streaming
- Pricing on connection basis

Chirp Probe Cross-Traffic Inference



New Ideas

Probing multiple hops

- Chirp-Sandwiches to probe routers
  - "down the path"
- IP-tunneling
  - Monitor packets at intermediate point of path
  - Verification for Chirping and Sandwiches
- Network calculus (max-plus algebra)

Probing buffer at core router

- Passive inference

Tech Transfer

- Stanford (SLAC)

  Chirps in PingER as freeware for monitoring
  - C+ code for sending Chirp Probes
  - 10 Msec precision
  - Visualization tools for link properties

  IP tunneling
  - Infrastructure at Rice ready
- CAIDA (chirping as a monitoring tool)
- UC Riverside (Demystify Self-similarity)
- Sprint Labs (queue-sizes at core routers)

Effort 2

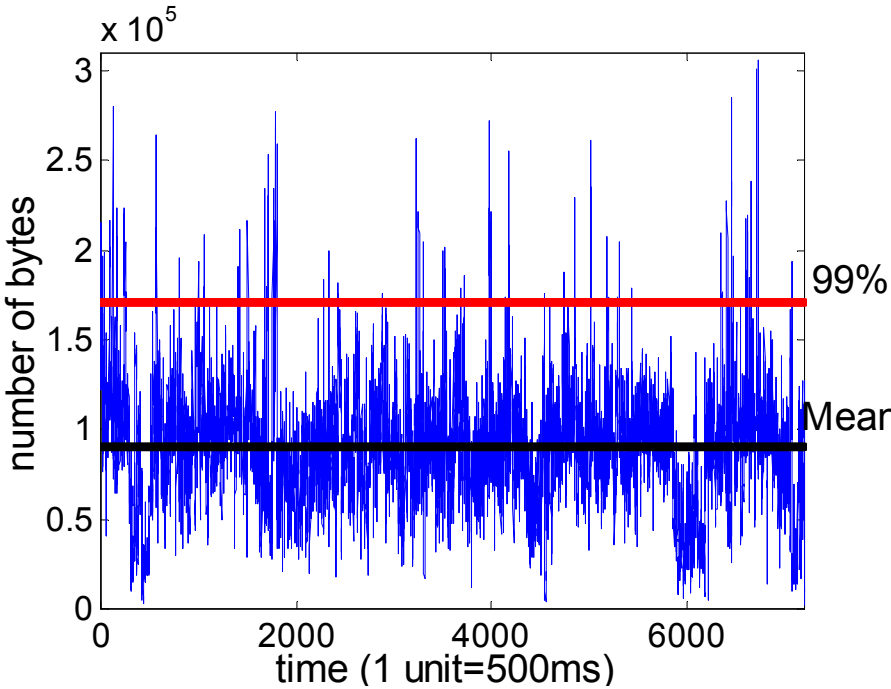
Connection-level Analysis and Modeling of Network Traffic

Aggregate Traffic at small scales

- Trace:
  - Time stamped headers
- Large scales
  - Gaussian
  - LRD (high variability)
- Small scales
  - Non-Gaussian
  - Positive process
  - Burstiness

Objective :
  - Origins of bursts

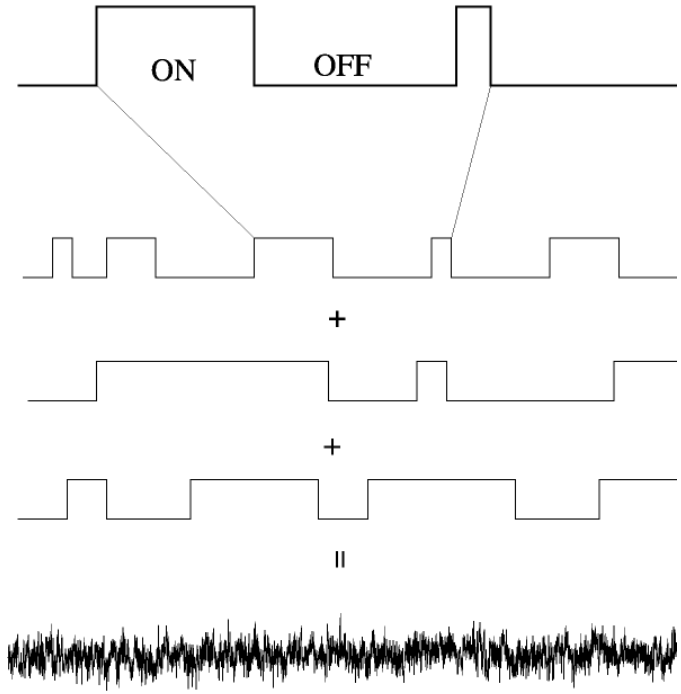
Auckland Gateway (2000)
Aggregate Bytes per time



Kurtosis - Gaussian : 3
- Real traffic: 5.8

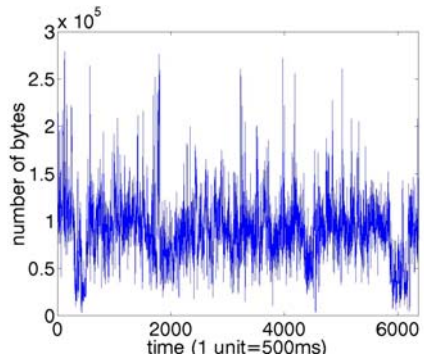
Bursts in the ON/OFF framework

- ON/OFF model
  - Superposition of sources
  - Connection level model
- Explains large scale variability:
  - LRD, Gaussian
  - Cause: Costumers
  - Heavy tailed file sizes !!



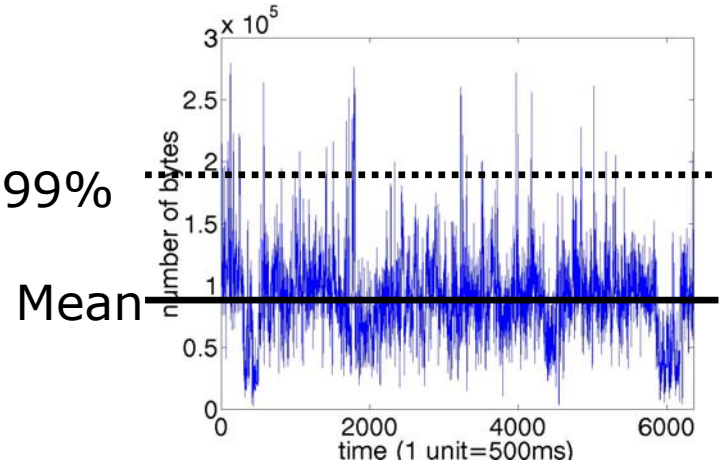
- Small scale bursts:
  - Non-Gaussianity
  - Conspiracy of sources ??
  - Flash crowds ??

    (dramatic increase of active sources)



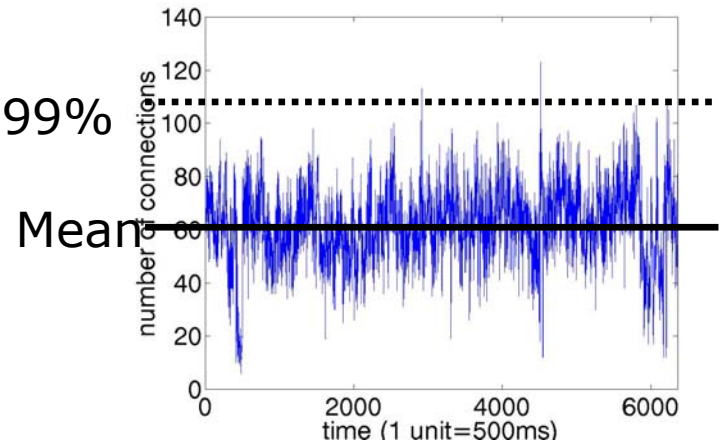
Non-Gaussianity: A Conspiracy?

Load: Bytes per 500 ms



- The number of active connections is close to Gaussian; provides no indication of bursts in the load

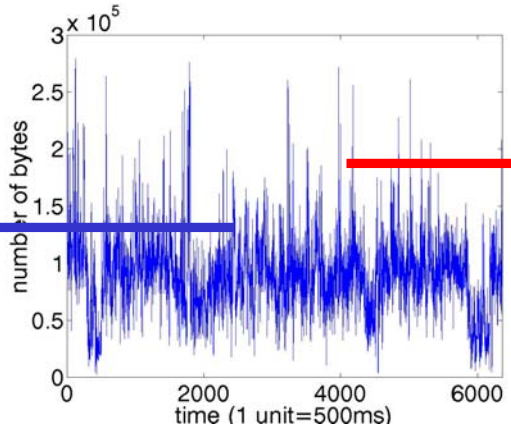
Number of active connections



- Indication for:
  - No conspiracy of sources
  - No flash crowds

Non-Gaussianity: a case study

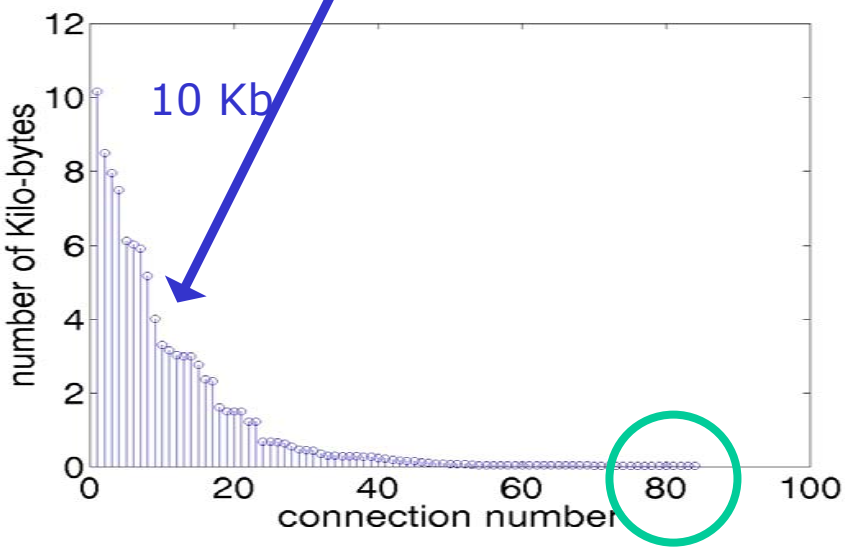
Typical Gaussian arrival (500 ms time slot)



Typical bursty arrival (500 ms time slot)

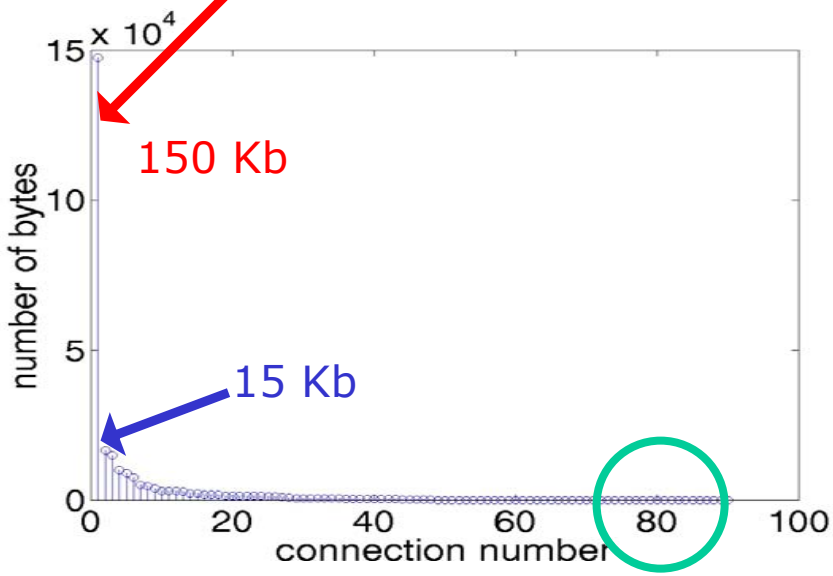
Histogram of load offered in same time bin per connection:

Considerable balanced "field" of connections



Histogram of load offered in same time bin per connection:

One connection dominates

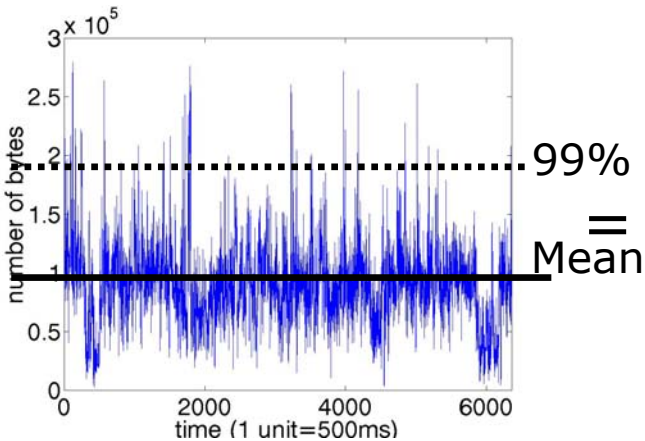


Non-Gaussianity and Dominance

Systematic study: time series separation

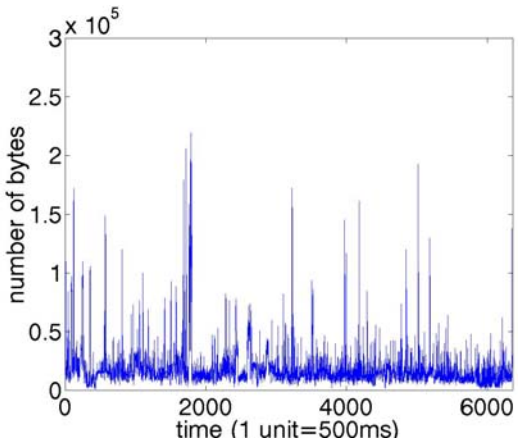
- For each bin of 500 ms:

  remove packets of the ONE strongest connection
- Leaves "Gaussian" residual traffic



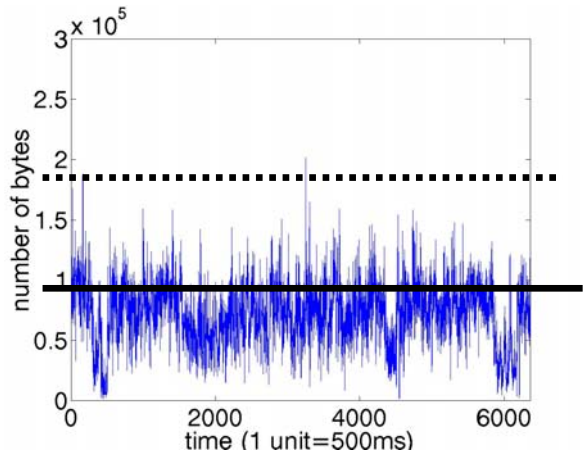
Overall traffic

=



1 Strongest connection

+



Residual traffic

Separation on Connection Level

Definition:

- Alpha connections:

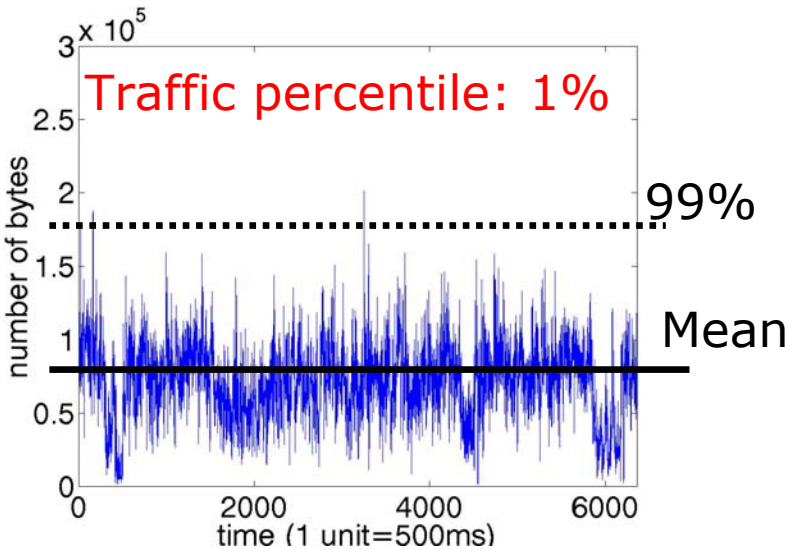
  Peak rate > mean arrival rate + 1 std dev

- Beta connections: Residual traffic

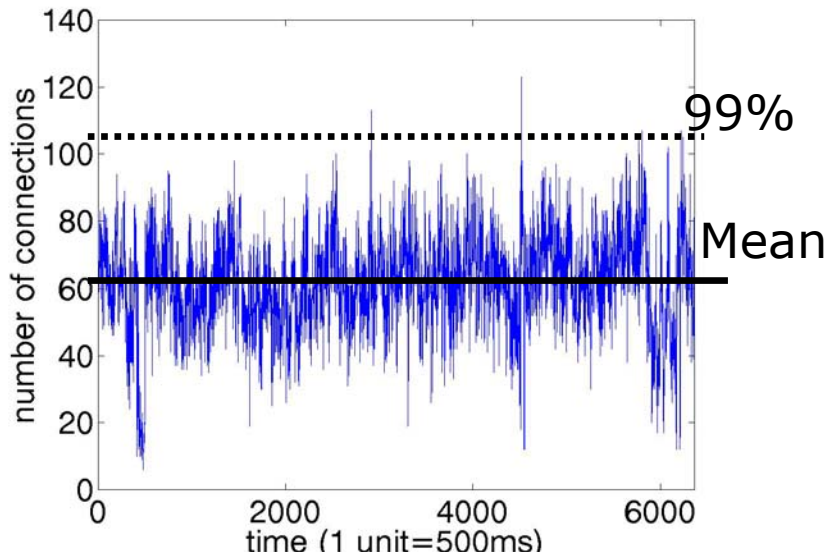
- C+ analyzer (order of sec)
- Separation is more efficient (less accurate) using multi-scale analysis

Beta Traffic Component

- Constitutes main load
- Governs LRD properties of overall traffic
- Is Gaussian at sufficient utilization (Kurtosis = 3)
- Is well matched by ON/OFF model



Beta traffic



Number of connections = ON/OFF

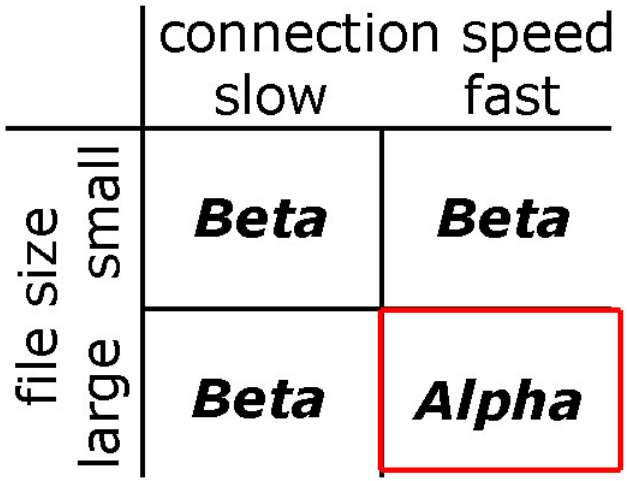
Origins of Alpha Traffic

- Mostly TCP (flow & congestion controlled).
- HTTP, SMTP, NNTP, etc.
- Alpha connections tend to have the same source-destination IP addresses.
- Any large volume connection with the same e2e IP addresses as an alpha connection is also alpha.

→ Systematic cause of alpha:

Large file transfers over high bandwidth e2e paths.

Simple Connection Taxonomy



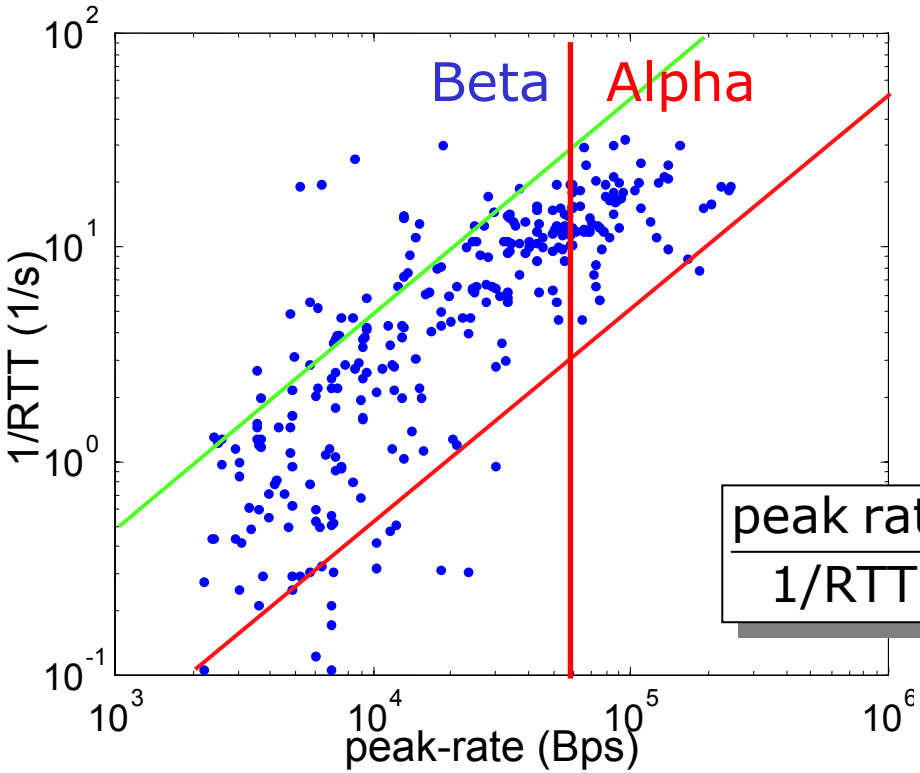
Bursts arise from large transfers over fast links.

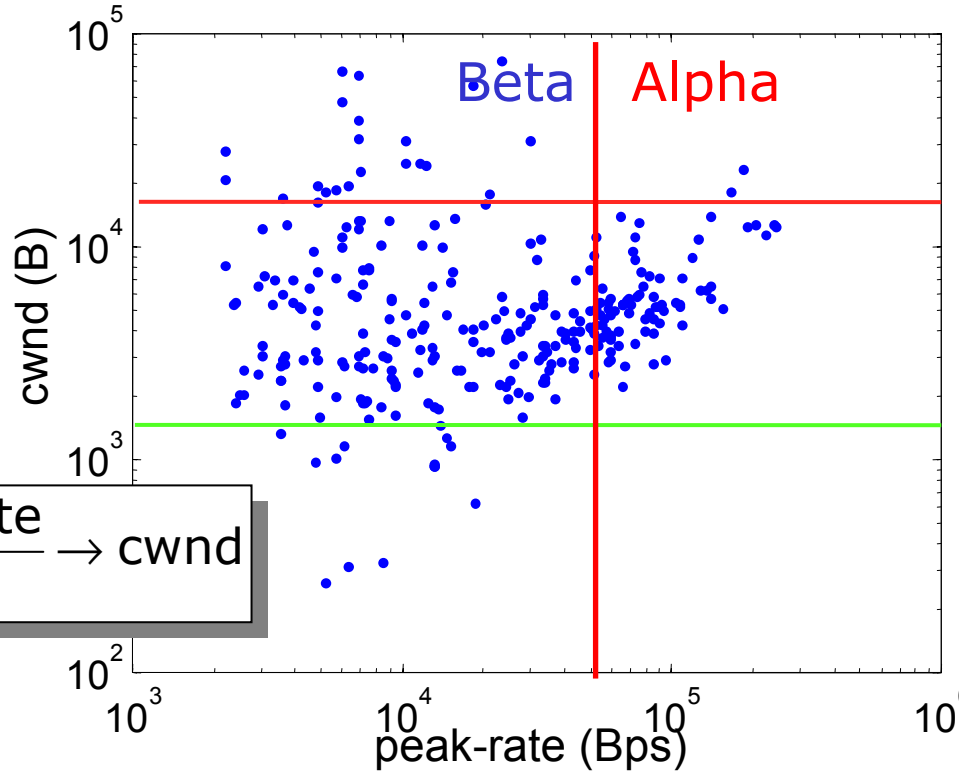
This is the only systematic reason

$$\text{bandwidth} = \frac{\text{cwnd}}{\text{RTT}}.$$

Cwnd or RTT?

Colorado State University trace, 300,000 packets





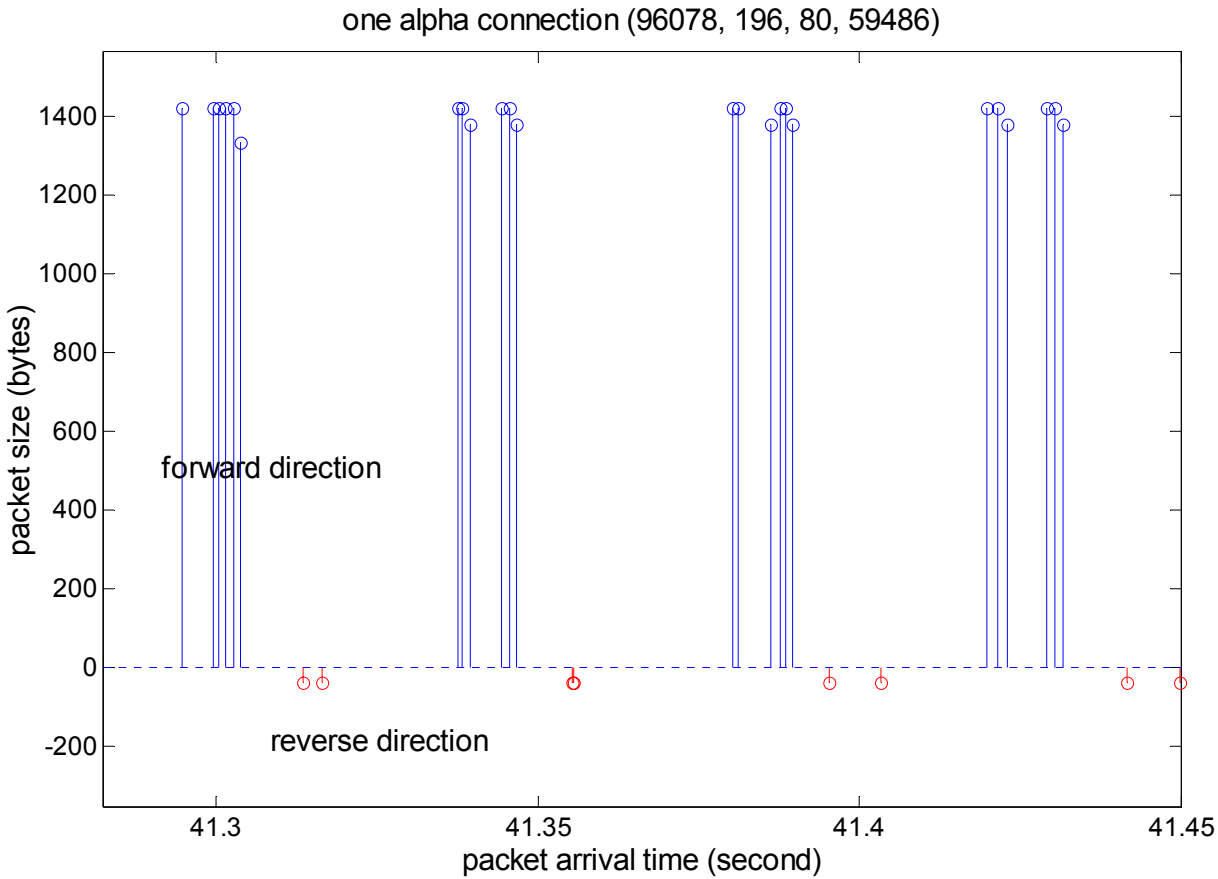
$$\frac{\text{peak rate}}{1/\text{RTT}} \rightarrow \text{cwnd}$$

Correlation coefficient=0.68

Correlation coefficient=0.01

RTT has strong influence on bandwidth and dominance.

Examples of Alpha/Beta Connections



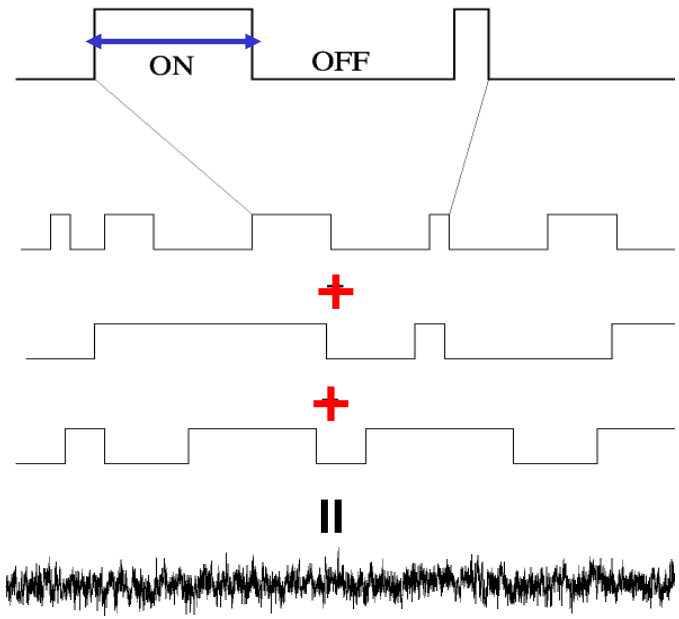
Alpha connections burst because of short round trip time, not large TCP window

Modeling of Alpha Traffic

- ON/OFF model revisited:

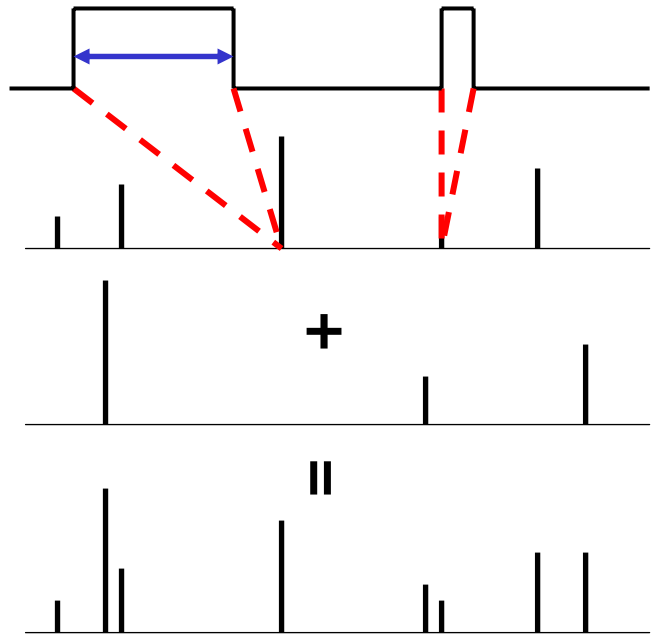
High variability in connection rates (RTTs)

Low rate = beta



fractional Gaussian noise

High rate = alpha



stable Levy noise

Modeling of Alpha Traffic

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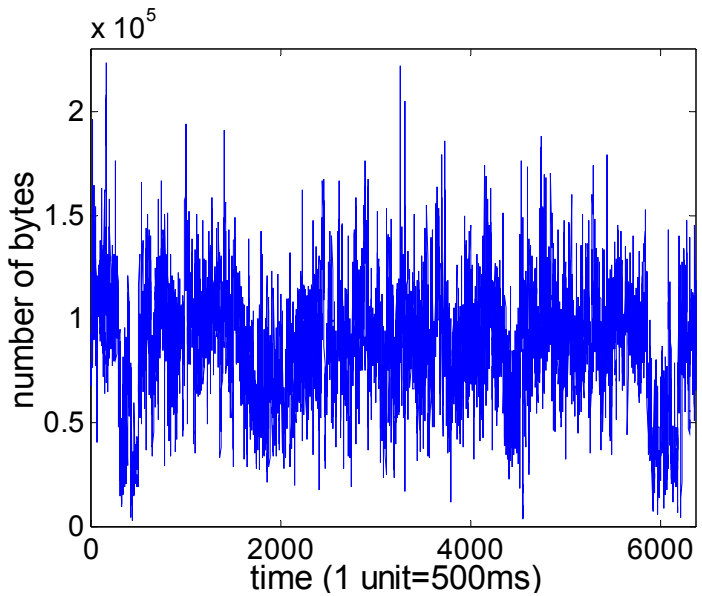

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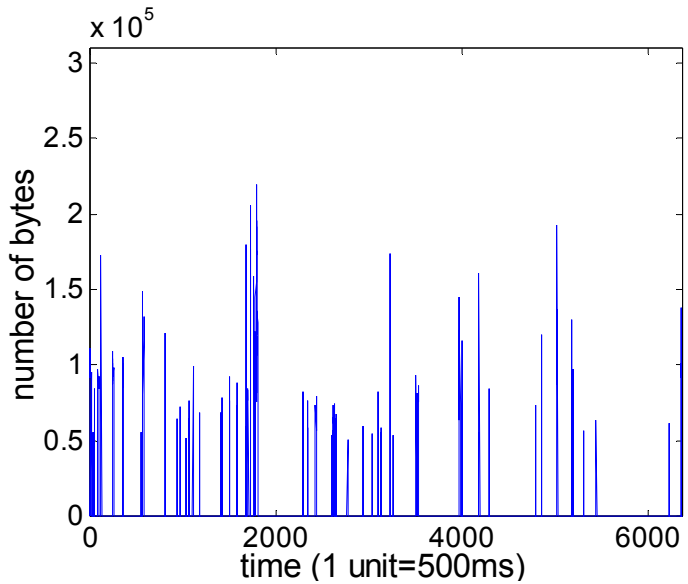

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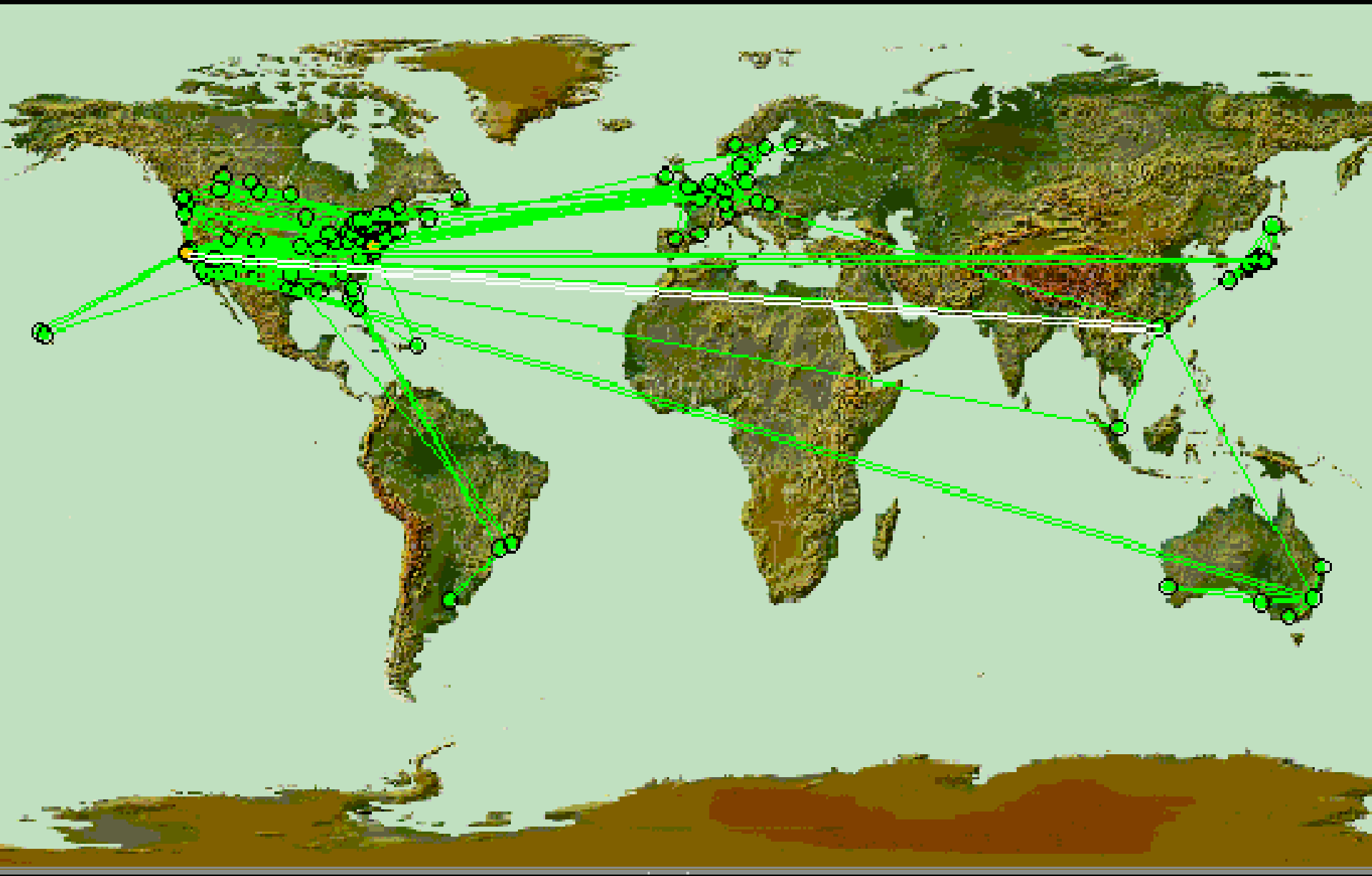
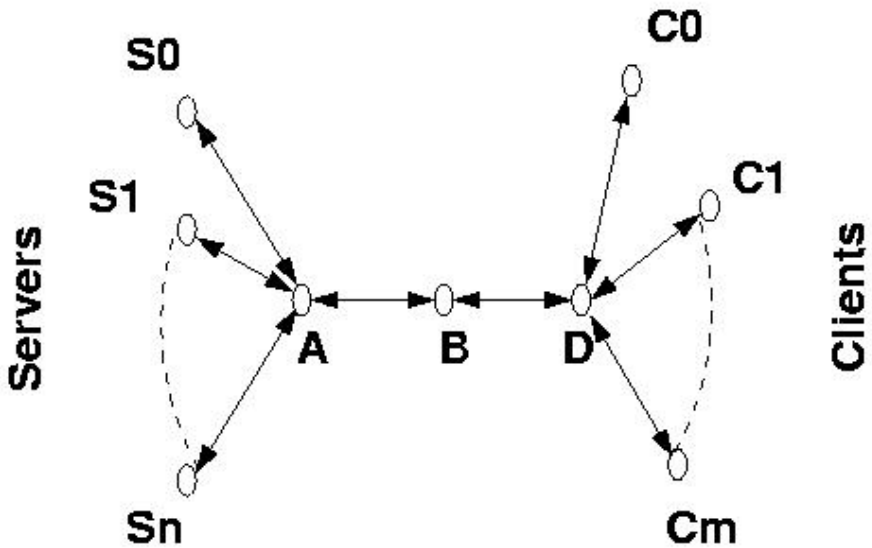


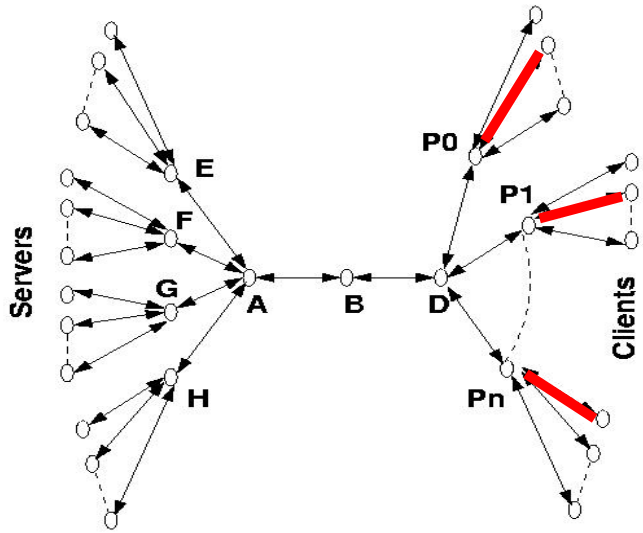
Impact: Simulation

- Simulation: ns topology to include alpha links

Simple: equal bandwidth



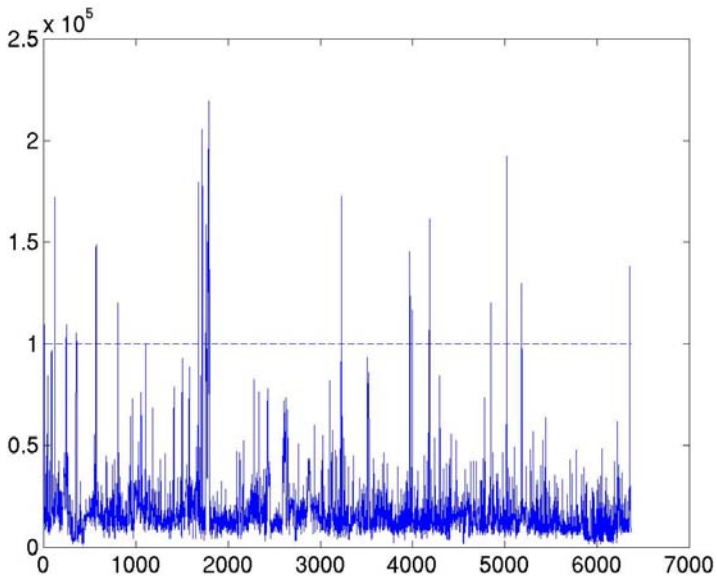
Realistic: heterogeneous end-to-end bandwidth



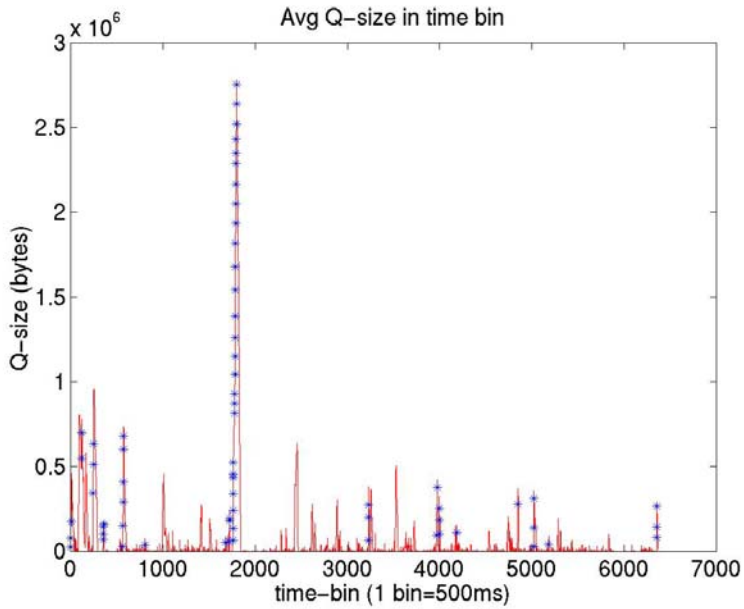
- Congestion control
- Design and management

Impact: Performance

- Beta Traffic rules the small Queues
- Alpha Traffic causes the large Queue-sizes
  (despite small Window Size)



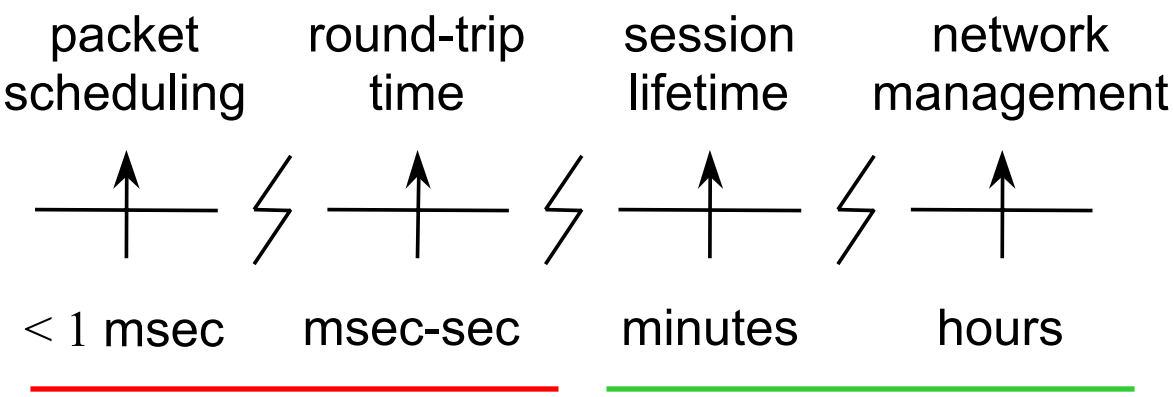
All Alpha *Packets*



Queue-size with Alpha *Peaks*

Multiscale Nature of Traffic

- Multifractal
  - Small time scale
  - Mixture Gaussian - Stable
  - Network topology
  - Control at Connection level
- LRD
  - Large time scales
  - approx. Gaussian
  - Client behavior
  - Bandwidth over Buffer



Structure: Multiplicative Additive

Ongoing Work

- Versatile efficient additive/multiplicative models (fast synthesis, meaning of model parameters)
- Impact of Alpha traffic on Performance
- Goal: Obtain performance parameters directly from network and user specifications

- Monitoring tool for network load (freeware) using chirps (Caida, SLAC)
- Verification/"internal" measurements using IP-tunneling

Summary

- Alpha traffic (peak rate > burst threshold)
  - Few connections. Responsible for bursts
  - Origin: Large transfer over high bandwidth paths
  - High bandwidth from short RTT
- Beta traffic (residual):
  - Main load. Responsible for LRD
  - Origin: Crowd with limited bandwidth
  - Gaussian at sufficient utilization

- Connection level analysis: parameter estimation drastically simplifies using multi-scale analysis
- Statistical modeling: requires novel multi-scale models (mixtures of additive and multiplicative trees)